

New Approaches to Studying Auditory Processing in Marine Mammals

James J. Finneran
Space and Naval Warfare Systems Center Pacific
Biosciences Division, Code 71510,
53560 Hull Street
San Diego, CA 92152
phone: (619) 767-4098 fax: (619) 553-0899 email: james.finneran@navy.mil

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LONG-TERM GOALS

The goals of the proposed effort are to enhance our understanding of the manner in which marine mammals process and respond to complex, real-world sounds by developing new experimental approaches to studying marine mammal auditory perception. The results of this study would provide new methodologies to enable the study of more complex features of auditory perception such as subjective stimulus similarity/dissimilarity and auditory template matching.

OBJECTIVES

The study aimed to develop novel techniques, based upon previous studies with birds (Dooling and Okanoya, 1995), for studying auditory perceptual similarity in a California sea lion (*Zalophus californianus*) and a bottlenose dolphin (*Tursiops truncatus*). It was proposed that subject response time (RT) would provide a useful metric of perceptual similarity.

The specific objectives were to (1) train the subjects for a task in which a conditioned response was provided upon detection of a change in a repeated background stimulus (i.e., an auditory discrimination task), (2) use subject RTs measured in a pure-tone discrimination task to demonstrate the effectiveness of the method for describing perceptual categorization, and (3) demonstrate the effectiveness of the method for studying the discrimination of complex real-world sounds.

APPROACH

A psychophysical task is designed to study the auditory discrimination capabilities of California sea lions and bottlenose dolphins. For this task, a subject remains attentive while a background sound is presented repeatedly, and presents a conditioned response upon detecting any change from background conditions (Figure 1). A sea lion is trained to wear a pair of headphones in a quiet room and to press a paddle upon the detection of a change, and a dolphin is similarly trained to station in a pool and to whistle upon detecting a change. Two types of trials are presented: *change trials* in which a background tone alternates with a “change” sound, and *catch trials* in which the background is repeated without a change. Correct responses (i.e., responding in the presence of a change or

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withholding response when no change is present) are both rewarded with fish reinforcement. Subject response time (RT) is measured for all trials by measuring the delay between the onset of a change in the background and the onset of the conditioned response. These data are analyzed in order to determine if RT is a reliable indicator of the subjective difficulty of discriminating stimuli.

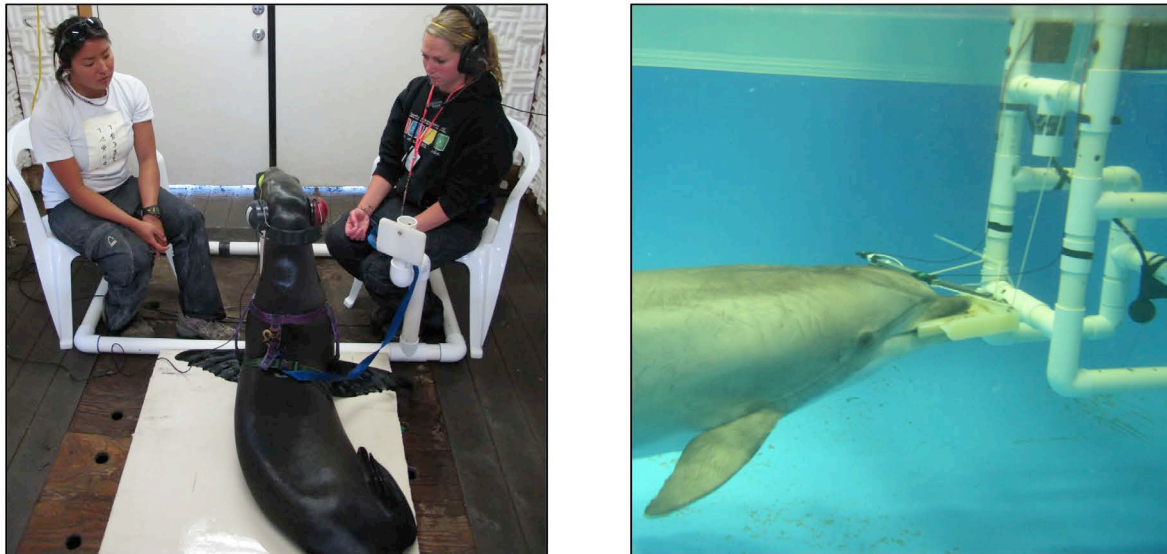


Figure 1. A California sea lion (left) and a bottlenose dolphin (right) participating in an auditory discrimination task. Subject RTs were determined by measuring the instants when the sea lion moved to press the paddle and when the dolphin produced the whistle response.

WORK COMPLETED

The sea lion and the dolphin were trained for the discrimination task, and custom software was designed to produce the required stimuli and record subject RTs. The two subjects participated in experimental sessions in which they were required to discriminate between tones that were identical in terms of frequency, duration, and envelope, but differed in terms of SPL. Data collection comprised individual sessions in which each SPL was compared to a standard background stimulus of constant SPL. Each SPL included in the experiment acted as the background in successive sessions, and a test matrix was completed when each SPL had acted as the background once. Data from a matrix was therefore composed of the subjects' discrimination RTs for all possible SPL comparisons. These data were then analyzed to determine the relationship between RT and perceptual similarity.

Following testing with pure tones, the sea lion was trained to discriminate between harmonic “bark” vocalizations recorded with three individual California sea lion vocalizations in the wild. Testing was conducted with the three unmodified vocalizations (V1, V2, V3) in addition to versions of each vocalization that had been high-pass filtered to remove the lowest-frequency components (V1HP, V2HP, V3HP). This portion of the experiment was similar to that conducted with tonal stimuli in that each session used one of the six vocalizations as a background, and the sea lion was required to respond when the background vocalization alternated with any other vocalization. Vocalization SPLs were randomized over a 6 dB range in order to ensure that the sea lion was not performing an amplitude discrimination.

RESULTS

Training of the discrimination behavior was achieved relatively rapidly; the performance of both subjects was sufficient for data collection after one to two months of training. For initial analysis of the data from each subject, all trials of equal SPL difference were pooled together. The sea lion's correct-detection percentage for change trials ranged from 94-100% when the SPL difference was 4 dB or greater. For comparisons with a 2-dB difference, performance was at 58% indicating that this amplitude difference was near the sea lion's discrimination threshold at 8 kHz. This result was similar to discrimination thresholds previously obtained with California sea lions (Moore and Schusterman, 1976), and suggested that the data were representative for this species. Data for the dolphin were similar; performance was between 93-100% at amplitude differences greater than 4 dB, and degraded to 77% at 2 dB. Histograms of RTs were generated for the data pooled according to SPL difference (Figure 2). The histograms were generally positively skewed, a feature that is characteristic of RT data. The central tendencies of the histograms decreased with increased difference between the SPLs of tones; thus, shorter RTs were associated with higher correct-discrimination probabilities and were indicative of larger subjective difference between tones.

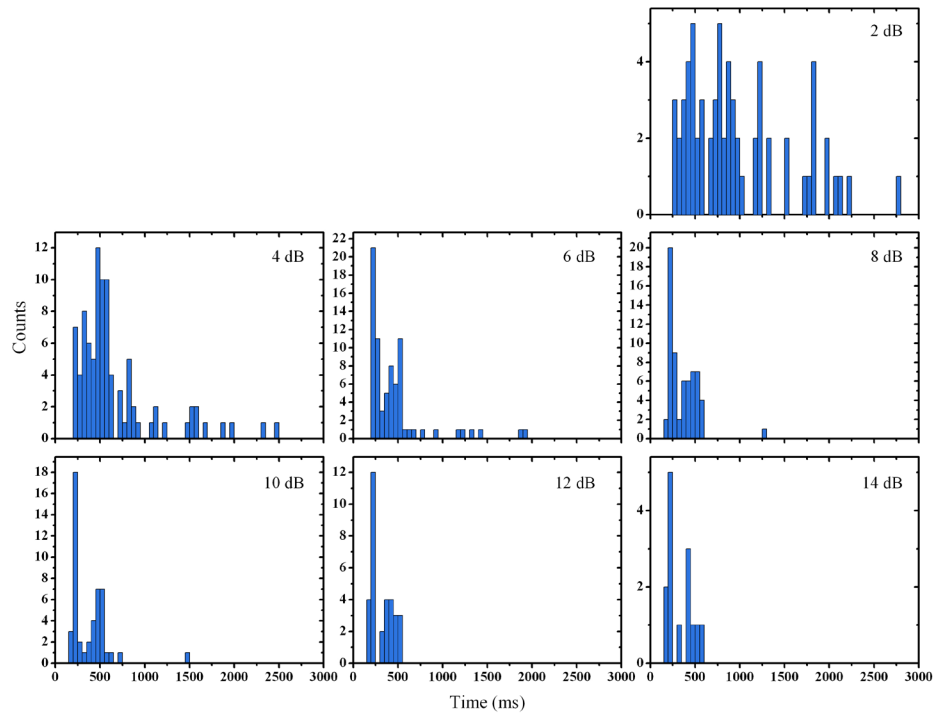


Figure 2. Distributions of California sea lion RTs (in ms) for all possible amplitude differences in a pure-tone discrimination study. Amplitude differences are given in the upper right of each plot. Data in each plot are pooled from all trials with a particular difference in amplitude (e.g., trials comparing 54 dB with 56 dB are pooled together with those comparing 60 dB with 62 dB, 50 dB with 52 dB, etc.) Note the decrease in central tendency with increased difference in tone level.

The RT data from the subjects' matrices were analyzed using multidimensional scaling (MDS) analysis (Dooling and Okanoya, 1995). Using RT as a proxy for perceptual similarity, an MDS analysis algorithm was used to create 2-dimensional "perceptual maps" where subjectively similar stimuli were located in relatively close proximity to one another (Figure 3). Tones with similar SPLs

were located in close proximity to each other in the perceptual maps. This confirmed that the subjects perceptually organized tones based on amplitude. The maps were similar to those obtained with humans and birds in previous experiments (Dooling *et al.*, 1987), and indicated that the methods from this study are suitable for studying subjective perception of acoustic stimuli in sea lions and dolphins.

Transfer from the pure-tone discrimination task to one using a training set of sea lion vocalizations was completed in less than a month, suggesting that the methods used in this study represent a robust and easily trained procedure for studying the discrimination of simple and complex sounds. The median RTs for four different discrimination conditions were compared (Figure 4): a single individual's unmodified vocalization with its high-passed counterpart (*Intra-voc UM/HP*; e.g., V1 and V1HP), unmodified vocalizations with high-passed vocalizations from other individuals (*Inter-voc UM/HP*; e.g., V1 and V2HP), unmodified vocalizations with unmodified vocalizations from other individuals (*Inter-voc UM*; e.g., V1 and V3), and high-passed vocalizations with high-passed vocalizations from other individuals (*Inter-voc HP*; e.g., V2HP and V3HP).

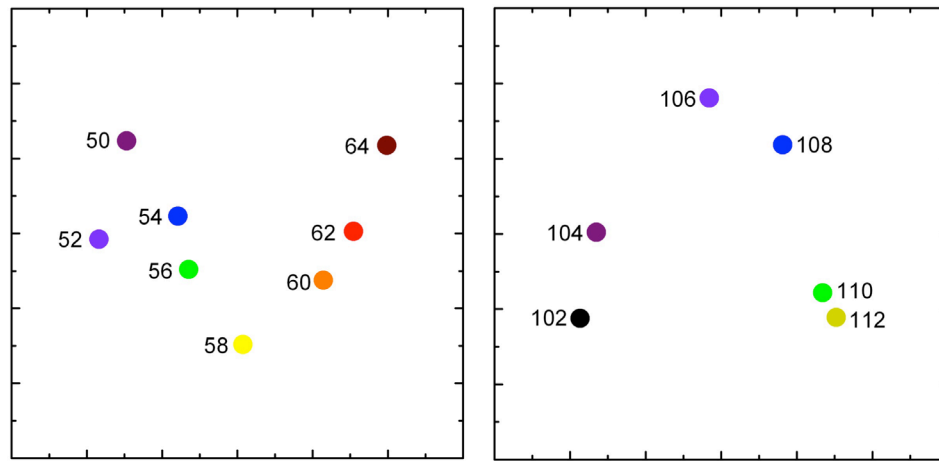


Figure 3. Two-dimensional “perceptual maps” of tonal stimuli, varying only in amplitude, for a California sea lion (left) and a bottlenose dolphin (right). The maps were created by analyzing average RTs using a multidimensional scaling algorithm. Numbers next to each point represent the sound pressure level of the tones (in dB re 20 μ Pa for the sea lion, dB re 1 μ Pa for the dolphin). Points that are located in close proximity were perceived by the subjects as being similar.

Analysis indicated that median RTs for the *Intra-voc UM/HP* and *Inter-voc UM/HP* discriminations were significantly different, with *Intra-voc UM/HP* discriminations having the longest RTs and *Inter-voc UM/HP* discriminations having the shortest RTs. The *Inter-voc UM* and *Inter-voc HP* conditions had very similar median RTs and were not significantly different than any other conditions.

The results of the vocalization discrimination study can be interpreted in light of the pure-tone discrimination study. First, the unmodified and the high-passed vocalizations from the same individual (*Intra-voc UM/HP* condition) appeared to be the most similar for the sea lion. Vocalizations from the *Inter-voc UM/HP* were perceptually less similar than the *Intra-voc UM/HP* condition, an expected result, as the *Inter-voc UM/HP* condition had the most acoustically different stimuli within trials. Although the sea lion found the comparisons of vocalizations from the same individual to be the most similar,

the median RT associated with those discriminations was 248 ms. When compared to the RT distributions for the pure-tone discrimination task (Figure 2), this median RT is still relatively fast. Therefore, although the *Intra-voc UM/HP* condition had the longest median RT, the vocalizations were still easily discriminated. This suggests that low-frequency components may be a perceptually salient part of sea lion vocalizations, an interesting result, as the majority of ambient noise occurs at low frequencies and otariid hearing thresholds increase with decreasing frequency below 1000 Hz (Mulsow and Reichmuth, 2010).

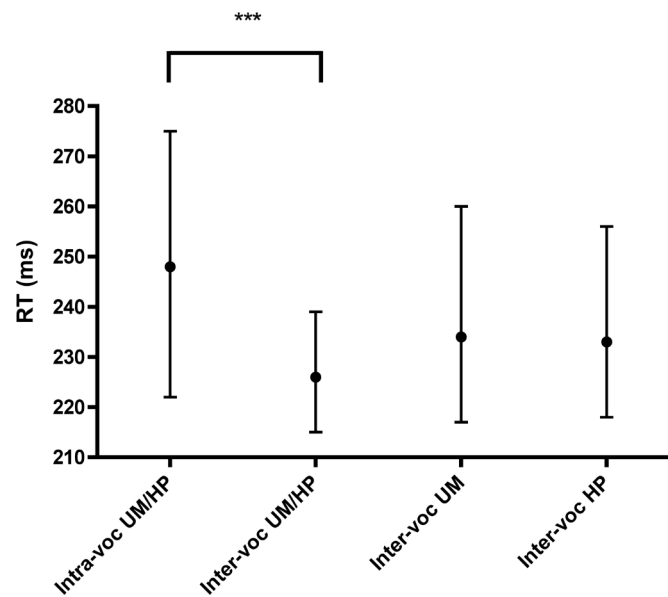


Figure 4. Median RTs (and interquartile ranges) for a vocalization discrimination task with a California sea lion. Four conditions of discrimination trials using unmodified (UM) and high-pass filtered (HP) California sea lion barks are shown (see text). The difference between *Intra-voc UM/HP* and *Inter-voc UM/HP* RTs was highly significant ($p < 0.001$, Kruskal-Wallis Test followed by Dunn's Multiple Comparison Test). Other differences were not significant ($p > 0.05$)

IMPACT/APPLICATIONS

The similarity of the results to those previously obtained with birds, and humans suggest that the methods developed here are a valid means of studying the subjective perception of acoustic stimuli in marine mammals. These methods are easily trained with captive subjects, and they appear to be readily generalized to a variety of stimuli, from simple pure tones to complex real-world sounds. The ease of training these methods makes them an attractive option for studying the subjective perception of complex acoustic stimuli in marine mammals, an aspect of auditory processing that is difficult to assess using procedures such as traditional threshold audiometry.

RELATED PROJECTS

None

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